MISCELLANEOUS PAPER NO. 4-942

EFFECTS OF TREAD PATTERN ON THE SURFACE TRACTION OF TERRA-TIRES

by

J. L. Smith

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U. S. Army Materiel Command

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FOREWORD

The study herein was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) at the special request of the Marginal Terrain Vehicle Project Manager of the U. S. Army Materiel Command. The work was done by personnel of the Mobility Research Branch, Mobility and Environmental Division, under the general supervision of Messrs. W. G. Shockley and S. J. Knight and Dr. D. R. Freitag. The tests were performed by the Operations Section under the direction of Mr. A. B. Thompson. Mr. J. L. Smith, Chief of the Mobility Fundamentals Section, was the project engineer and prepared this report.

COL John R. Oswalt, Jr., was Director of WES during the test program and preparation of this report, and Mr. J. B. Tiffany was Technical Director.

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SUMMARY

This study consisted of two test series conducted using seven Terra-tires, of which one had a smooth surface and the other six had various tread areas and patterns. The first series was to determine w at effect adding tread to the Terra-tires on the MTV would have on its slope-climbing and pull-producing ability. Tests were conducted on a strong fat clay with a wet surface, and each test consisted of five passes with a single wheel powered at 20 percent slip, or locked in a full skid.

The second series evaluated four materials for possible use in sponson construction. These tests were conducted with the same seven Terra-tires on both wet and dry surfaces of each material. The wheel was either free rolling or locked.

In the in-soil tests, analysis of all five passes showed that the treaded tires, regardless of pattern, developed more traction and skid resistance than did the smooth tire. Tread pattern appeared to have little influence on the P/W values developed, but tread area influenced these values significantly. Tires with either too little or too much tread area performed poorly. The Terra-Grip and the nondirectional bar tread appeared to have the best combination of tread area and tread arrangement of the tires tested. Performance in the locked-wheel tests followed the same general pattern as in the tests with the powered wheel.

In the tests to evaluate sponson materials, the performance of the free-rolling wheel showed no significant differences, regardless of the material used or the surface condition. In the locked-wheel tests, a given material generally offered greater resistance to a given tire when the material was dry, but there were some exceptions, notably on carborundum-impregnated aluminum. The highest skid resistance was developed on dry silicon carbide, the lowest on wet structural aluminum.

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EFFECTS OF TREAD PATTERN ON THE SURFACE TRACTION OF TERRA-TIRES

PART I: INTRODUCTION

Background

1. The Marginal Terrain Vehicle (MTV) (see fig. 1) was field tested in April 1967 at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The MTV had difficulty negotiating even gentle slopes in a strong fat clay when the surface was wet and slick. The suggestion was made that the smooth Terra-tires being used on the MTV could not penetrate the slick layer of wet surface soil to gain traction in the firmer soil beneath, and that the use of treaded tires might permit this penetration and thereby improve the slope-climbing ability. Consequently, Mr. James Carr, MTV Project Manager, requested that WES conduct a test program to provide information on the effect of tread pattern on surface traction.

2. Later, Mr. Carr requested that tests be added to determine the rolling- and sliding-friction characteristics of different tread patterns on several structural materials after it was observed that forward motion was denied the MTV not only because the tires developed too little traction in soil, but also because of the low frictional forces existing between the tires and the underside of the two sponsons.

Purpose

3. The specific objectives of the test program reported herein were:

   a. To determine whether treaded Terra-tires improved the pull-developing and the slope-climbing ability of the MTV operating on smooth, wet soil slopes.

   b. To determine the frictional resistance developed when the test tires were towed and skidded across several materials being considered for use in sponson construction for the MTV.

Scope

4. Laboratory tests were conducted

tread patterns. Tread patterns tested were nearly smooth (ribbed), Xtra-Traction (brand name), nondirectional bar, and the Terra-Grip chevron in these four variations: the tread as it originally came from the manufacturer; with two-thirds the tread height buffed off; with the original tread height, but with half the original tread area removed; and with the original tread height, but three-fourths the original tread area removed. These are illustrated in fig. 2. The Terra-tires used were 16X14.5-6R, and were deflected 18 percent of the section height. Except for the Terra-Grip with 1/3 tread area (G), the tread heights of all the treaded tires were nearly the same (0.30 in.) and except for the Xtra-Traction tire (A), the contact patch on any unyielding surface was nearly equal when the tires were at test inflation pressures and equal loads were applied. The load was 580 lb.

5. The Terra-tire used was approximately a 2/3-scale model of the tire actually used on the MTV. The load was scaled as the square of the size ratio, i.e. to 4/9 of that of the prototype. Inflation pressure was adjusted so that the deflection ratio (tire deflection/tire section height) of the model was the same as that of the prototype.

6. Tests were conducted in a high-strength, saturated fat clay with a flooded surface, using a powered wheel operated at 20 percent slip and a towed wheel in a free-rolling and a locked (skidding) condition. The in-soil tests were conducted on a flooded surface; tests on the different surface materials were on both wet and dry surfaces.

PART II: TEST PROCEDURES

In-Soil Tests

6. Fat clay, 95 percent saturated, was prepared in test sections 32 in. high by 64 in. wide by 54 ft long. All test sections had uniform strengths of approximately 100 cone index. After a test section was prepared, it was flooded with just enough water to cover the soil surface, and a test run as soon after flooding as practicable. Immediately before each traffic pass, soil strength was measured with a cone penetrometer* at regular intervals along the length of the test car. The tire was driven at a constant 20 percent slip in the first half of each test. This slip was chosen because it corresponds to a near-maximum pull condition for pneumatic tires operating in soil. In the last half, the wheel was locked in a full skid. Test data were continuously recorded electronically.* Each test consisted of five passes of a single wheel, to correspond to the five wheels on each track of the MTV that contact the soil. A duplicate of each test was run in an effort to ensure that test data were reliable. Data from the two tests were used to obtain an average value.

Tests of Materials

7. In this part of the test program, single-pass tests with each of the seven tread patterns were run on silicon carbide, Buna-S rubber, structural aluminum, and aluminum impregnated with carborundum, and the motion resistance was measured. All test procedures were the same as for the in-soil tests, except that the wheel was operated in a free-rolling (zero torque) and a locked (-100 percent slip) condition and tests were conducted on wet and dry surfaces.

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*U. S. Army Engineer Waterways Experiment Station, CE, Performance of Soils Under Tire Loads, Test Facilities and Techniques, by J. L. McRae, C. J. Powell, and R. D. Wismer. Technical Report No. 3-666, Report 1, Vicksburg, Mississippi, January 1965.

PART III: ANALYSIS OF DATA

In-Soil Tests

Powered wheel

8. The load from test to test was nearly constant, so performance could be evaluated in terms either of pull (P) or pull/load (P/W) with equal validity. Pull/load was chosen because the near-maximum P/W ratio for a pneumatic tire operating on flat, level, cohesive soil corresponds roughly to the maximum percent of slope that the loaded tire can climb. In addition, to extrapolate model pull results to a prototype, the model P/W must be multiplied by the prototype load (W).

9. Performance data (see table 1) are plotted in fig. 3. The average of the results of five passes was used in the analysis to evaluate sustained performance. For each test tire, P/W generally decreased with each additional pass. Performances of the treaded tires were far superior to that of the smooth tire. Average P/W values for three tires--the Terra-Grip with full tread (B) and half tread (F) area and the nondirectional bar tread (H)--were approximately equal to each other, and approximately seven times larger than the average smooth tire (E) performance value. The remaining treaded tires developed nearly equal average P/W values that were about four times that of the smooth tire. The direction of the tire tread did not influence P/W in the tires tested, as is shown when the performance of the nondirectional bar tread is compared with that of the full-tread Terra-Grip in fig. 3.

10. Lower P/W values were developed by the Xtra-Traction tread (A, fig. 3), which had 0.4 in. between treads, compared to those developed by the other treads (B, F, H), which had 1.5 in. between treads. These data indicate that unless there is a substantial separation between treads around the tire's circumference, the spaces between fill with soil, thereby producing essentially a smooth tire that cannot gain full traction.

11. The amount of tread area influences performance, but not enough tests were run to define the effect precisely. Results do indicate that the Xtra-Traction tire had too much tread area. Its performance was the poorest of the treaded tires. The Terra-Grip tire produced about the same P/W with full or half tread area, but a much smaller P/W when 3/4 of the tread area was removed. In this test program, the largest P/W values were obtained

when the tread area was evenly divided and arranged over the full soil-tire contact area and when at least half the original tread area was retained. However, the test program was limited and the effect that other possible distributions of tread might have on performance is not known.

12. Sufficient data were not available to determine definitely the effect of tread height, but the results of tests with different tread heights on the Terra-Grip tire indicate that, for a given tire, performance improves as tread height increases. The range tested did not permit the establishment of an optimum maximum tread height.

Locked wheel

13. In these tests, the skid resistance, P, was measured as the locked wheel was towed across the surface. The effect of tread pattern on P/W when tires were tested with wheels locked (full skid) for five passes is shown in fig. 4. Generally, tires that produced high P/W (positive pull) in the 20 percent slip tests also produced high skid resistance (negative pull) in the locked-wheel tests and in the same order. As in the 20 percent slip tests, the largest first-pass P/W value was achieved by the Terra-Grip tire (Γ) with 1/2 tread area. However, except for smooth-tire performance, the absolute magnitudes of the P/W values obtained were smaller in the locked-wheel tests and the division into groups of nearly equal performance was not as well defined.

Materials Tests

Free-rolling wheel

14. Regardless of the tire tread pattern or the surface material, rolling resistance produced when the tires were towed across the various test materials were too small to be precisely measured by the test system used, and no significant differences in wheel performance could be detected (see table 2).

Locked wheel

15. Average P/W values obtained in the locked-wheel tests on the four materials are listed in table 3. P/W values from tests on the silicon carbide and carborundum-impregnated aluminum were significantly larger than those from tests on Buna-S rubber and structural aluminum. The largest difference (0.546) was between the smooth tire and the Terra-Grip with 1/2 tread area

and full tread height on silicon carbide with a wet surface. The smallest difference (0.098) was between the nondirectional bar tread and the Terra-Grip with full tread area and full tread height tested on structural aluminum with a dry surface. However, no tire tread pattern consistently performed better or worse than any other on either the wet or dry surfaces. Since the main purpose of these tests was to determine the overall skid resistance developed by a given material, the P/W for all the tires was averaged for a given test condition, and this average was used in the evaluation of the various materials.

16. In tests on a dry surface, the highest average P/W values were achieved on silicon carbide, with values decreasing for impregnated aluminum, Buna-S rubber, and structural aluminum, in that order. On a wet surface, nearly equal average P/W values were developed on silicon carbide and impregnated aluminum that were more than twice those of the Buna-S rubber and structural aluminum. Larger P/W values were reached when surfaces of silicon carbide, Buna-S rubber, and structural aluminum were dry. A surprising result of this program was that the average P/W value on the impregnated aluminum surface was higher when the surface was wet than when it was dry.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

17. From the information presented herein and for the conditions tested, the following conclusions are drawn:

In-soil tests

a. Regardless of the tread pattern, treaded Terra-tires on wet surfaces developed considerably more traction and skid resistance than did the smooth Terra-tire.

b. Details of the tread patterns appear to have little influence.

c. For the range tested in this study, performance improves as tread height increases for a given tire.

d. The area covered by tire tread significantly influences performance. Tires with either too much or too little tread area performed poorly. For the tires tested in this study, the combination of tread area and tread spacing of the Terra-Grip and the nondirectional bar tread Terra-tires appears near optimum.

Tests of materials

e. Free-rolling wheels on either wet or dry surfaces developed rolling resistance too small to be measured precisely by the test system used.

f. On dry surfaces, the highest skid resistance was developed on silicon carbide.

g. Skid resistance values attained on impregnated aluminum and silicon carbide with wet surfaces were nearly equal to each other, and more than twice that on Buna-S rubber or structural aluminum.

Recommendations

18. It is recommended that:

a. The smooth Terra-tires of the MTV be replaced with treaded Terra-tires similar to either the Terra-Grip or the nondirectional bar tread.

b. Carborundum-impregnated aluminum and silicon carbide be studied further as possible construction materials for the sponsons of the MTV, and particularly, that the wearing action of their abrasive characteristics on the vehicle Terra-tires be investigated.

Table 1

In-Soil Test Results

Tire*	Pass	Pull/Load**	
		Powered-Wheel Tests	Locked-Wheel Tests
Xtra-Traction Terra-tire (A)	1	0.271	-0.191
Full Tread Area	2	0.182	-0.142
Full Tread Height	3	0.171	-0.124
	4	0.160	-0.114
	5	0.151	-0.101
	Avg	0.187	-0.134
Terra-Grip (B)	1	0.466	-0.245
Full Tread Area	2	0.268	-0.210
Full Tread Height	3	0.273	-0.180
	4	0.245	-0.162
	5	0.288	-0.181
	Avg	0.308	-0.196
Terra-Grip (C)	1	0.282	-0.183
Full Tread Area	2	0.211	-0.153
1/3 Tread Height	3	0.193	-0.117
	4	0.169	-0.109
	5	0.160	-0.131
	Avg	0.203	-0.139
Smooth (ribbed) Terra-tire (E)	1	0.074	-0.111
	2	0.048	-0.059
	3	0.037	-0.049
	4	0.036	-0.038
	5	0.035	-0.035
	Avg	0.046	-0.058
Terra-Grip (F)	1	0.541	-0.342
1/2 Tread Area	2	0.304	-0.190
Full Tread Height	3	0.295	-0.199
	4	0.250	-0.161
	5	0.232	-0.185
	Avg	0.324	-0.215
Terra-Grip (G)	1	0.360	-0.205
1/4 Tread Area	2	0.233	-0.180
Full Tread Height	3	0.176	-0.174
	4	0.139	-0.144
	5	0.159	-0.149
	Avg	0.213	-0.170
Nondirectional Bar Tread Terra-tire (H)	1	0.466	-0.211
	2	0.367	-0.159
Full Tread Area	3	0.292	-0.185
Full Tread Height	4	0.278	-0.164
	5	0.288	-0.175
	Avg	0.338	-0.179

*Letters in parentheses are keyed to fig. 2.
**Two-test average.

Table 2

Free-Rolling-Wheel (Zero Torque) Results of Tests on Materials

Material	Tire*	Pull/Load** Dry Surface	Pull/Load** Wet Surface
Silicon Carbide	A	0.000	-0.003
	B	-0.010	-0.003
	C	-0.003	+0.005
	E	-0.010	-0.007
	F	-0.010	-0.001
	G	-0.003	-0.001
	H	-0.001	-0.003
Carborundum-Impregnated Aluminum	A	-0.007	-0.003
	B	-0.009	-0.003
	C	-0.002	-0.001
	E	-0.007	-0.007
	F	-0.009	-0.000
	G	-0.006	-0.002
	H	-0.002	0.000
Buna-S Rubber	A	-0.008	-0.013
	B	-0.008	-0.008
	C	-0.002	0.000
	E	-0.006	-0.007
	F	-0.009	0.000
	G	-0.005	-0.003
	H	-0.003	-0.006
Structural Aluminum	A	-0.006	0.000
	B	-0.010	-0.006
	C	-0.001	+0.003
	E	-0.009	-0.005
	F	-0.010	-0.004
	G	-0.003	0.000
	H	-0.004	-0.003

*Letters are keyed to Fig. 2.

** Two-test average.

Table 3
Locked-Wheel Results of Tests on Materials

Material	Tire*	Pull/Load**	
		Dry Surface	Wet Surface
Silicon Carbide	A	-0.793	-0.979
	B	-0.943	-0.703
	C	-1.078	-0.857
	E	-1.171	-1.137
	F	-0.748	-0.591
	G	-0.811	-0.667
	H	-0.876	-0.770
	Avg	-0.917	-0.815
Carborundum-Impregnated Aluminum	A	-0.793	-0.930
	B	-0.775	-0.829
	C	-0.755	-0.942
	E	-0.859	-0.837
	F	-0.695	-0.777
	G	-0.687	-0.716
	H	-0.883	-0.711
	Avg	-0.778	-0.820
Buna-S Rubber	A	-0.594	-0.522
	B	-0.639	-0.386
	C	-0.595	-0.377
	E	-0.483	-0.182
	F	-0.650	-0.301
	G	-0.621	-0.295
	H	-0.964	-0.474
	Avg	-0.649	-0.362
Structural Aluminum	A	-0.504	-0.532
	B	-0.496	-0.403
	C	-0.529	-0.352
	E	-0.510	-0.385
	F	-0.569	-0.241
	G	-0.548	-0.308
	H	-0.594	-0.247
	Avg	-0.536	-0.353

*Letters are keyed to Fig. 2.
**Two-test average.

Fig. 1. Marginal Terrain Vehicle

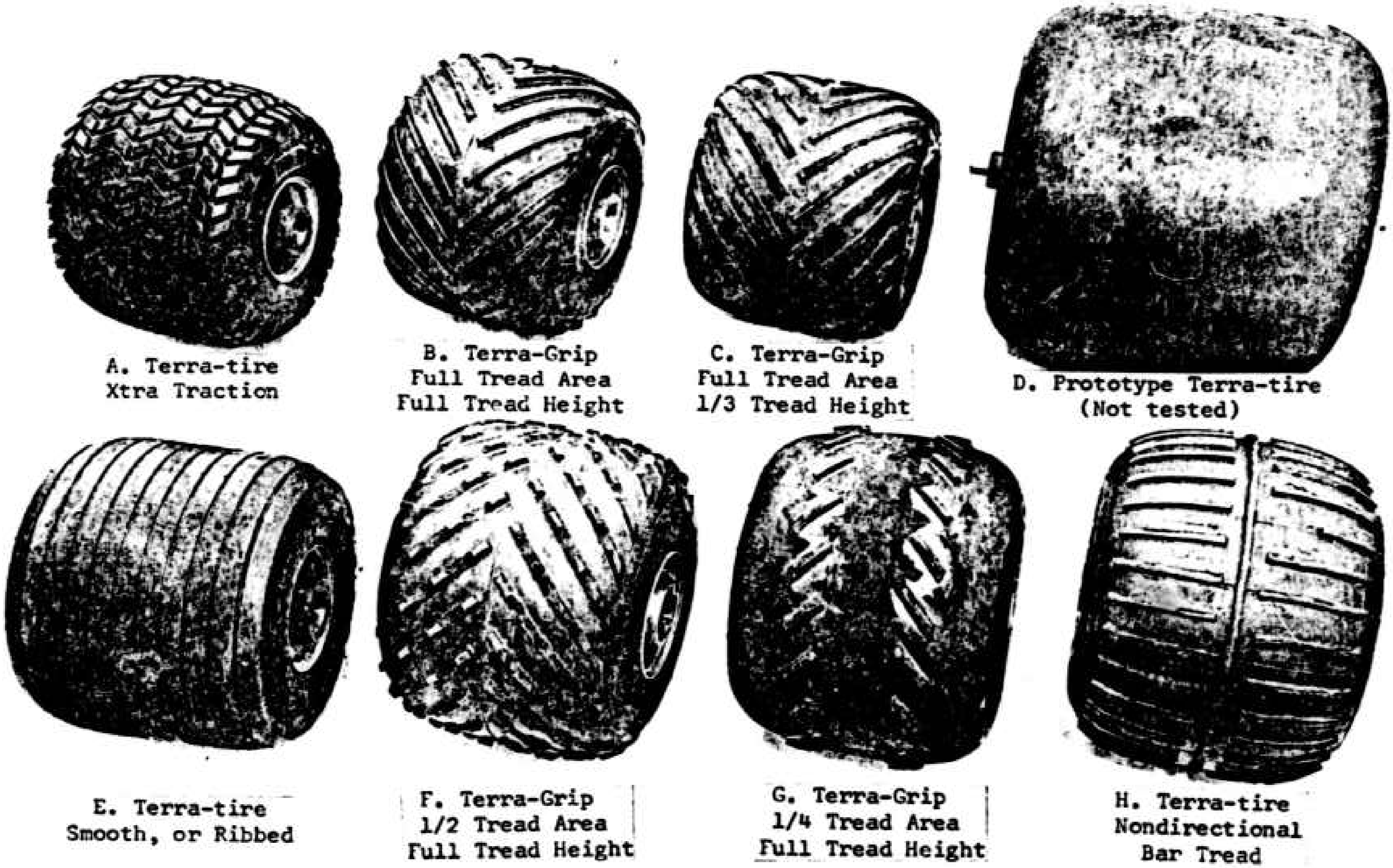
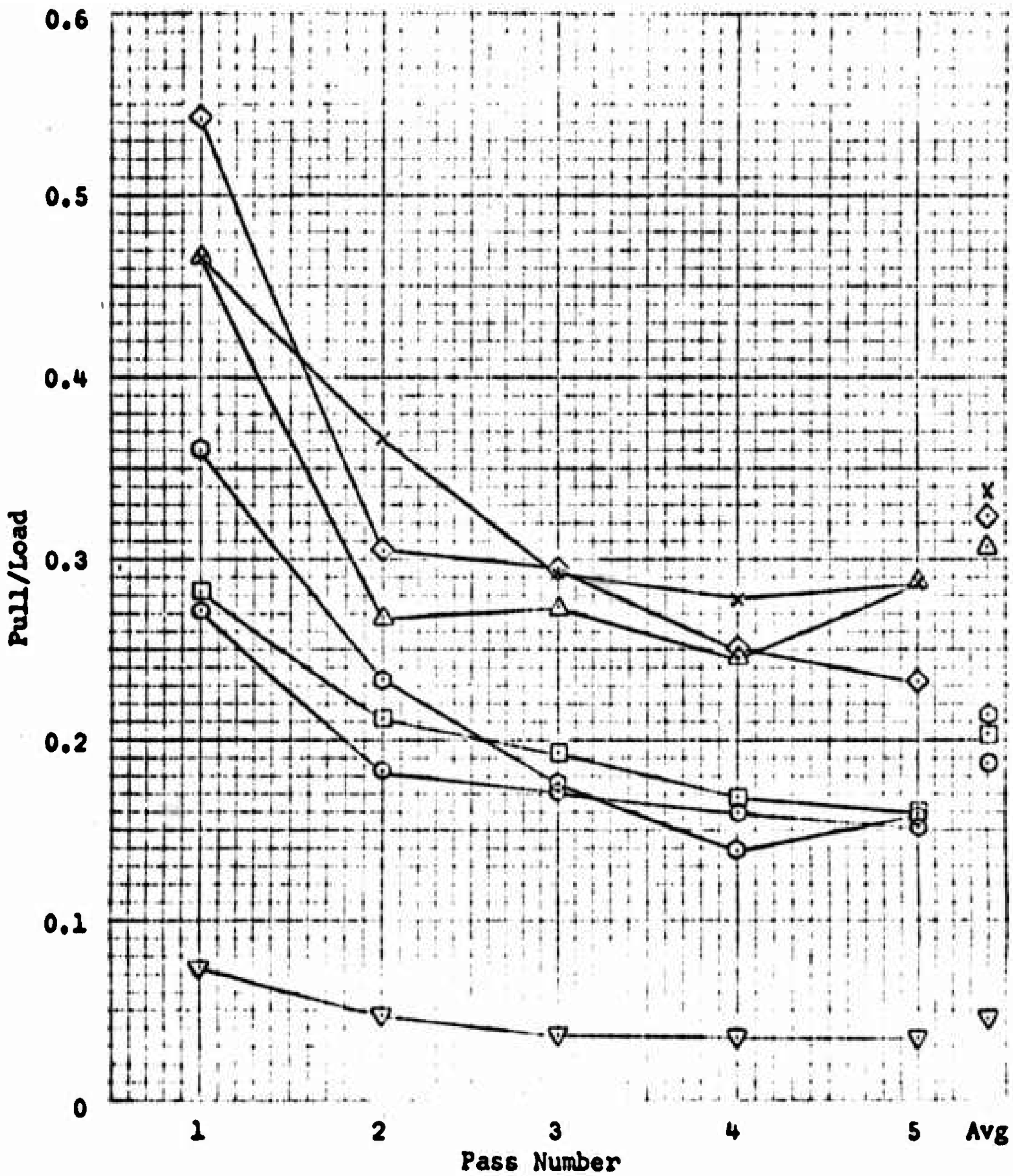


Fig. 2. Two-thirds-scale model Terra-tires used in test program



Symbol	Tire*
⊙	A
△	B
⊡	C
▽	E
◇	F
⊙	G
X	H

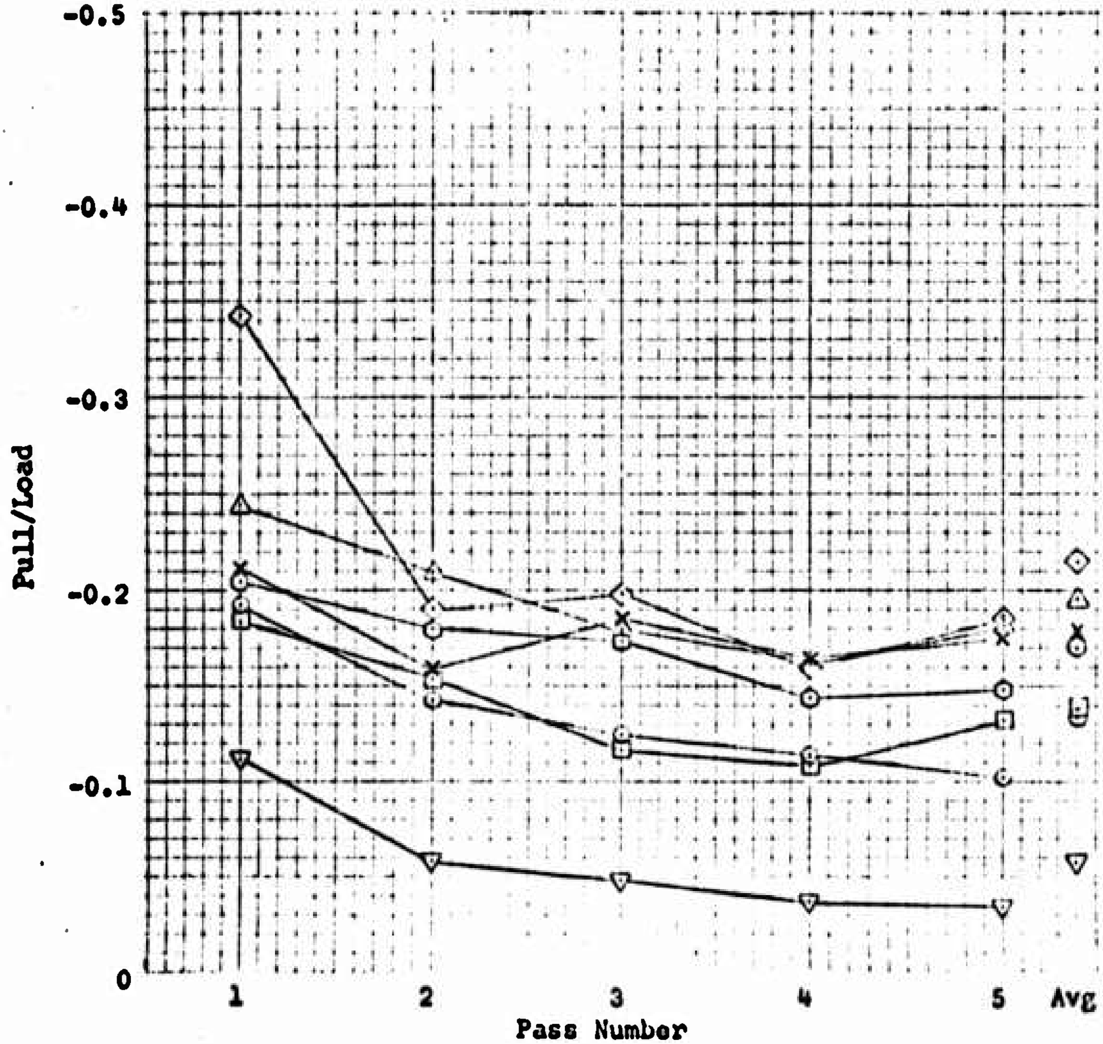
*See Fig. 2.

EFFECT OF TIRE TREAD PATTERN ON PERFORMANCE

Powered-Wheel Tests
(20 percent slip)

580-lb Test Load
18 Percent Tire Deflection

Fig. 4



Symbol	Tire*
⊙	A
△	B
⊡	C
▽	E
◇	F
⊙	G
×	H

*See Fig. 2.

EFFECT OF TIRE TREAD PATTERN ON PERFORMANCE

Locked-Wheel Tests

580-lb Test Load
18 Percent Tire Deflection

Fig. 4

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